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Tensile Strain and Temperature Characterization of FBGs in Preannealed Polymer Optical Fibers

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Abstract-- **Our thermal and tensile strain experiments show that fiber Bragg gratings (FBGs) in preannealed polymer optical fibers (POFs) can offer more stable performance and extend the operating temperature and strain range without hysteresis.**

I. Introduction

Due to the much lower Young's modulus and much higher thermo-optic coefficient of polymethyl methacrylate (PMMA) [1], Bragg gratings in PMMA POFs have great potential for sensing temperature and strain with higher sensitivity and wider tunability than its silica counterpart [1-4]. This of course requires that the length of the PMMA POF is short due to the large material loss of PMMA, and that one does not want to operate at high temperature, due to the low melting temperature of PMMA. In order to avoid the material loss problem of PMMA, one could fabricate FBGs in perfluorinated POF, but it is not quite clear whether this material is photosensitive [1]. One option is to glue a short length of POF with grating to a silica fiber. On the other hand, previous reports have indicated that a preannealing process before the inscription can relieve the frozen-in stress induced by the fiber drawing process [4] and increase the linear operation temperature range of POF FBGs [4]. However, the influence of the preannealing process on FBGs in commercial POFs and in particular their strain sensitivity performance, which is crucial to the practical applications of POF FBGs, has not been given a scrutinous examination yet.In this paper we report on an investigation into the properties of FBGs in preannealed step index POFs and compare it with the properties in the non-annealed fiber. The formation dynamics, the temperature response, the thermal stability, and the tensile strain features of the gratings in the two kinds of POFs are studied and compared. Different behaviours from what previously were reported are indentified and discussed. We show that preannealing the fiber can greatly increase the performance of POF FBGs and at the same time keep all the advantages of the POF.

II. Experiments

A. POFs and FBG Writing

The gratings in this study were fabricated in PMMA single mode POF with a core doped with Polystyrene (MORPOF02, Paradigm Optics). The fiber has an outer diameter of 115um and a core diameter of 4um, as shown in the inset of Fig.1. The preannealing is carried out by putting a length of POF in an oven at 80°C for two days. The gratings were inscribed using a 30mW cw HeCd laser operating at 325nm (IK5751I-G, Kimmon) and a phasemask customized for 325nm with uniform period 1048.7nm (Ibsen Photonics). The writing setup is shown in Fig.1. The laser irradiance at the fiber was 10Wcm^{-2} and the exposure time was 60 minutes, which resulted in a grating wavelength around 1553nm, as shown in the inset of Fig.1.

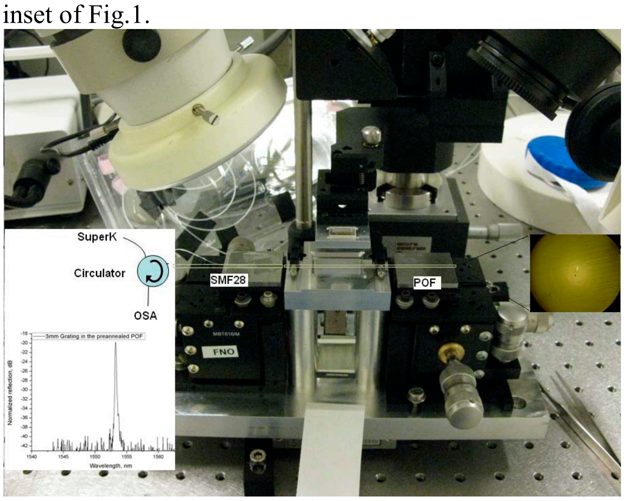

Fig. 1. The POF FBGs writing and monitoring setup.

The growth of the 3mm gratings formed in both the normal (un-annealed) POF and the preannealed POF were monitored in reflection during the inscription using a silica fiber circulator, a broadband laser source (SuperK, NKT Photonics), and an optical spectrum analyzer (OSA, Ando AQ6317B). Short lengths of fiber (<10cm) were used due to the high attenuation of the POF, which is ~3dB/cm at 1550nm.

B. Temperature characterization of FBGs

The temperature response of a 3mm grating in both an annealed POF and a normal POF, is shown in Fig. 2(a, c) and 2(b, d), respectively. The grating section of the POF was heated up. A thermo couple was used to measure the real temperature around the grating with an uncertainty around 0.3°C. All gratings were fabricated with the same exposure time of 60 minutes. Twenty minutes was allowed for the temperature of the grating to stabilize at each new temperature setting before the resonance wavelengths and the peak intensity were measured [2, 3]. A linear response is observed up to a critical temperature

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of 60°C in the normal POF. By annealing the POF we see that the critical temperature is increased to about 80°C. In both cases the sensitivity below the critical temperature is about -100pm/°C.

Two new gratings were temperature-cycled to study hysteresis. First we heat them up to 75°C and 55°C, respectively (red dots), followed by cooling down to room temperature (red triangles). These temperatures are below the critical temperature and as expected we see in Figs. 2(a-b) a linear response and no hysteresis. Then we heat both up to 85°C (black squares), which is above the critical temperature, followed by cooling down to room temperature (black triangles). Now we observe a marked hysteresis of the resonance wavelength. For the annealed POF we measure a permanent shift in the resonance wavelength of about -4 nm (Fig. 2(a)), but there is no noticeable drop in the reflected peak intensity (Fig. 2(c)). For the normal POF the shift is 5 times stronger, about -20nm (Fig. 2(b)) and there is a drop of 10dB in the reflected peak intensity (Fig. 2(d)).

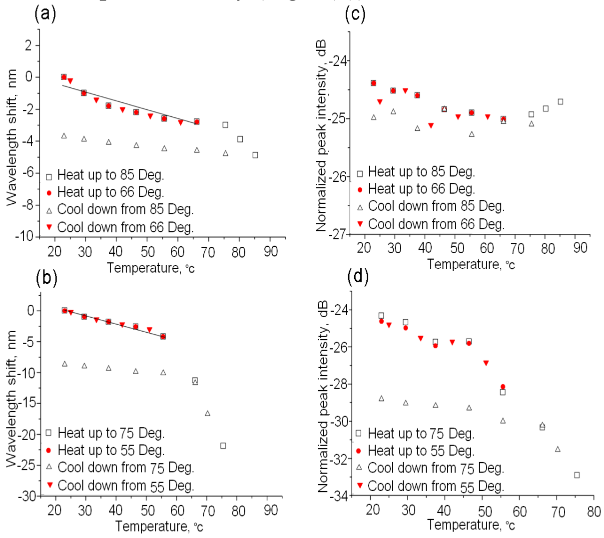

Fig. 2. (a-b) Bragg wavelength and (c-d) peak intensity versus temperature during heating and cooling cycles. Top row shows the annealed POF. Bottom row shows the normal POF.

C. *Tensile strain characterization of FBGs*

We have also characterized the static strain response of the POF FBGs. The ends of the POF were clamped to two micro-translation stages. One stage was fixed and used to butt-couple the POF to the silica fiber. The other stage can move longitudinally to manually apply axial strain to the grating with a low loading speed [3]. The gratings were left to stabilize for about 10 minutes each time the tensile strain was changed, before measuring the reflection spectrum. From the results shown in Figs. 3(a-d), we see that the wavelength sensitivity has an approximately constant value of about 1.37 pm/με and 1.30 pm/με for the annealed and normal POF, respectively. In contrast, the reflected peak intensity drops suddenly above a certain critical strain, which is increased from about 2.5% to 3.0% by annealing the fiber. A strain loading cycle experiment was carried out in order to examine whether any hysteresis could be detected. The POF FBG's were stretched by 3.75% and released again. The results, shown in Figs. 3(c-d), showed no noticeable hysteresis for the annealed fiber, whereas the normal POF showed a small difference in the resonance wavelength of about 3nm.

III. Conclusions

We have shown that hysteresis of wavelength shift and peak intensity appears in POF FBGs above a temperature of 75°C in a preannealed POF and 55°C in a normal POF. Comparing with FBGs in a normal POF, the grating in the preannealed POF can offer much more stable peak intensity during the temperature cycling below the threshold temperature. Strain tuning of the polymer FBGs has demonstrated that the operation strain region without hysteresis is 2.5% for the normal POF and 3% for the preannealed POF. The stain sensitivities of both gratings were similar, i.e., 1.3pm/με for the normal POF and 1.37pm/με for the preannealed POF. There was a significant improvement of the stability of the peak intensity, no peak splitting at high strain loading was found, and much higher strain can been applied to the preannealed POF grating.

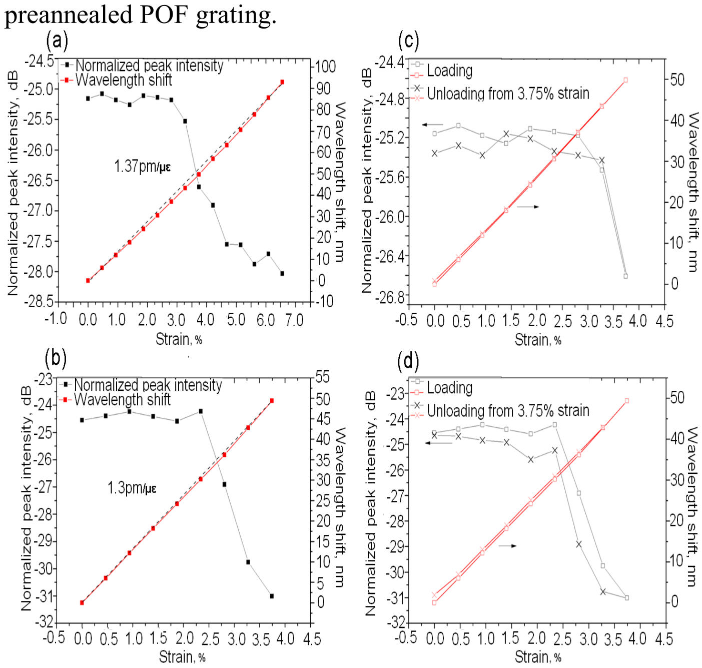

Fig. 3. (a-b) Strain sensitivity of Bragg wavelength and reflected peak intensity. (c-d) Same strain sensitivity during loading with 3.75% strain and downloading again. Top row shows the annealed POF. Bottom row shows the normal POF.

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